More effective winter maintenance method for cycleways

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ABSTRACT

Increasing cycling as a means of personal travel could generate environmental benefits if associated with a corresponding decrease in car-based transport. In promoting cycling during winter, the maintenance service level of cycleways is of importance. Earlier studies have indicated that the Swedish public is unsatisfied with the service levels provided on cycleways during wintertime. Normally, in Sweden cycleways are cleared from snow through ploughing and gritted for skid control. In this paper, field studies testing an unconventional winter maintenance method using a power broom for snow clearance and salt for de-icing will be presented. The field studies were evaluated through road condition observations, measurements of friction, a questionnaire survey, interviews and bicycle measurements. The method using a power broom for snow clearance and salt for de-icing provided a higher service level than winter maintenance methods traditionally used, but it was about 2 to 3 times more expensive. The method has greater potential in regions, such as southern Sweden, with low snow accumulations but with major ice formation problems, compared to regions with a colder climate. The cyclists did notice the improved maintenance service level provided with the method used in the field study, but although cyclists stated, that the road condition was important in their decision to cycle or not, it could not be concluded, that the enhanced service level generated a higher winter cycling frequency.

INTRODUCTION

Background

A high incidence of bicycle usage for personal travel is desirable, primarily for environmental reasons, assuming it is associated with a corresponding decrease in car-based transport. The variation in cycle flows between seasons is large, and the flow during summer is nearly three times greater than during winter (*1*). The decrease in cycling frequency during winter is thought to be largely due to less favourable weather conditions, but worse road conditions is also a possible explanation (*2*, *3*). The road condition is also a safety issue, since many one-vehicle accidents among cyclists are caused by hazardous road conditions (*1, 4, 5, 6*). Regarding these accidents, as well as the environmental benefits associated with fewer car trips, improving the winter maintenance service level on cycleways can make benefits to the society.

Surveys (*3, 7*) have indicated that the Swedish public is unsatisfied with the service levels provided on cycleways during the wintertime, and that improved winter maintenance on cycleways could lead to increased cycling. However, there is a difference in intentions and actual behaviour, and it is uncertain, whether improved winter maintenance would actually lead to a higher cycling frequency. Further studies are needed to know, if it is possible to improve the maintenance service level on cycleways during winter, what methods are to be used, and if the increased service level leads to a higher cycling frequency.

Winter maintenance of cycleways in Sweden

In Sweden, cycleways are normally cleared from snow through ploughing and gritted for skid control. In gritting, abrasives are often used since it, opposed to sand, do not need to be heated or mixed with salt to prevent freezing and increase friction, even when covered by a thin layer of snow. However, this coarse, rough-edged material creates a problem with punctures in bicycle tyres, and it creates a safety hazard in spring before it is swept up (*1, 5, 6*).

Chemical methods, usually application of sodium chloride (NaCl), are often used on roadways but rarely on cycleways. Most municipalities stopped using salt on footways and cycleways after receiving complaints from cyclists concerning rust on cycle chains and from pedestrians, whose clothes and shoes had been stained. Spreading salt in solution (brine) allows the salt dosage to be reduced considerably, which is desirable, considering the environmental effects from the use of salt. Brine is also preferred when de-icing cycleways since heavy traffic usually is needed for dry salt to work effectively.

The methods and equipment used for cycleway maintenance are usually the same as for ordinary roadways (*8*). In many cases, trucks, tractors, ploughs and sanding equipment are too large and heavy for this purpose and can cause damage to cycleways. It is also difficult for this type of equipment to pass through tunnels and narrow passages. However, in recent years, smaller vehicles more suitable for use on cycleways and footways, for example, the Multicar and the Mercedes Benz UX 100 have become available on the market. These vehicles can be easily equipped for a variety of applications, providing a good economical situation, since it enables the same vehicle to be used during both winter and summer maintenance operations (*9*).

Objective

This paper presents field studies testing unconventional methods for snow clearance and de-icing of cycleways. The objective of the studies was to find a method producing a higher maintenance service level than conventional methods do and to see to what extent improvements could be done, at what costs. The studies also aimed to see if the road users would notice any difference in the service level and if a higher maintenance service level would lead to increased winter cycling frequency.

METHOD

Field studies to evaluate different winter maintenance methods were performed in Linköping. Linköping is located in south central Sweden, and the city has about 93 000 inhabitants. Linköping has a well-developed network for bicycle traffic and a large number of cyclists owing to widespread commuting by bicycle and many cycling students. In Linköping, the problem with ice formation is major, and, hence, skid control is usually the most important winter maintenance measure on cycleways.

Pilot study

To find a winter maintenance method that could improve the service level of cycleways and to get experience of the problems resulting from certain maintenance methods, a pilot study was carried out in Linköping in 1999 (from February 22 to March 17). Traditionally, in Linköping cycleways are cleared through ploughing and skid control is attained by abrasives in 4 to 8 mm size. In the pilot study, two different and unconventional methods of snow clearance and skid control were tested on two selected cycleways. One of the methods used a traditional steel plough for snow clearance and graded gravel for skid control. The graded gravel consisted of natural granular stone particles washed and processed to obtain a size of between 2 and 5 mm. This test method was similar to the method normally used on cycleways in Linköping. However, it was still meant to produce a higher service level by using tougher starting criteria and the graded gravel with the purpose of reducing cyclists' problems with punctured tyres. The other test method used a front-mounted power broom for snow clearance combined with a brine spreader for de-icing. Using the power broom was meant to reduce any remaining layer of ice and snow, so that the salt dosage needed to achieve a bare surface could be minimised. The idea of this "brine method" came from Odense in Denmark (*10*), where a similar method had been used for winter maintenance on cycleways for several years. However, it was uncertain, if this method was applicable to Swedish winter climate.

The pilot study was evaluated through road condition observations and measurements of friction. Roadside interviews, catching commuters cycling to or from work to get their opinion of the tested methods, were also conducted. The experience obtained in the pilot study was used to exclude less suitable methods for further testing and as guidance for planning a large-scale study.

Large-scale study

A large-scale study was carried out during two winters (between October 1999 and March 2001). In this study a housing area, *Ekholmen*, within cycling distance (about 5 km) of a large workplace, *Saab AB*, in Linköping, Sweden, was used as a test area. Saab AB was considered suitable for the study, since it is the largest workplace in the city with frequent commuting by bicycle. In addition, Saab AB was included in a questionnaire survey conducted in 1998 (*3*), which provided this study with valuable background information.

All cycleways within the housing area of Ekholmen, as well as three major routes from Ekholmen to Saab AB, were included in the test area, resulting in a total of about 23 km of cycleway. In the test area, the cycleways were given a higher level of service than usual in Linköping by using the front-mounted power broom for snow clearance and brine, or on some occasions pre-wetted salt, for de-icing. The equipment used was almost the same as that used in the pilot study, but instead of a spraying boom for salt spreading, a spinner was used in the large-scale study. As in the pilot study, snow clearance and skid control were performed more frequently than on other cycleways, starting snow clearance at a snow depth of 1 cm loose snow and de-icing on every occasion where ice, snow or hoarfrost occurred. (In Linköping, snow clearance is normally started at a snow depth of 3 cm). It was also required, that cycleways should be cleared before 6.30 a.m. to certify, that most commuters would be provided with a high maintenance service level when cycling to Saab AB in the morning. Snowfall or other weather conditions creating a slippery surface during the day should be dealt with before 4 p.m., when commuters from Saab AB cycled home in the afternoon.

The effective clearing width of the power broom was about 2 m. Because most cycleways were 3 to 4 meters wide, at least two rounds were needed to clear the whole width of the cycleways, in particular after a heavy snowfall. Usually, one side of the whole cycleway network in the test area was maintained before a second turn was started. The main routes between Ekholmen and Saab AB were prioritised before transverse cycle routes, although concern was taken to get a practical maintenance route.

Road condition observations

In the large-scale study, as well as during the pilot study, observations of road surface conditions were conducted after almost each occurrence of snowfall or hoarfrost. For these observations, a method for roadways (*11*) modified (by the author in "Assessment of winter road conditions on cycleways" – unpublished) to better apply to cycleways was used. Observations were done on six cycleway sections within the test area and maintained with the "brine method", and on four cycleway sections used as controls and maintained traditionally. To picture the prevailing conditions for commuters cycling to Saab AB, most observations were performed around 7 o'clock in the morning. Each road condition observation were noted in a specific protocol, according to the modified instructions, and complemented with a photograph of the observed section.

Measurements of friction

As a complement to the road condition observations, measurements of friction were conducted, in particular during the pilot study. These measurements were performed with a Portable Friction Tester (PFT) developed at the Swedish National Road and Transport Research Institute (VTI) to measure friction on road markings in wet conditions (*12*). Since the PFT is reasonably small and handy, it was considered practicable in this case when measuring friction on cycleway surfaces, where it can be difficult to use other measuring devices. Further information concerning the operation of the PFT and the performance of the measurements is given in earlier work by the author (*13*).

Questionnaire survey

The large-scale study was also evaluated through a questionnaire survey performed in 2000 to get the road users opinion of the winter maintenance method tested. A total of 829 questionnaires were distributed to all employees at Saab AB living in the test area of Ekholmen, and to control groups in three other housing areas within about the same cycling distance from Saab AB as Ekholmen.

The questionnaire comprised 26 questions divided in two parts. The first part, including more general questions, was directed towards all the respondents, while the second part with more specific questions related to the large-scale study was addressed only to those, who cycled during wintertime.

Bicycle counts

Particularly during the second winter (2000/2001), the large-scale study was also evaluated through bicycle counts to conclude whether a higher maintenance service level produced by the “brine method” resulted in a higher winter cycling frequency. Manual counts were conducted at 5 occasions at 2 to 4 points at each occasion. All counts were performed in the morning with the purpose of counting commuters on their way to work. The time as well as weather and road conditions for each occasion are presented in Table 1. The counting points somewhat coincided with the cycleway sections observed during road condition observations and are therefore given the same labels: T1 and T3 within, and C1 and C3 outside the test area.

At each counting point, cyclists were registered according to their direction. The number of possible directions varied from 2 to 10 between the different points. In the analyses, the different directions were aggregated into groups of significance for the study. For example in measuring point C3, the total flow was of interest and hence all directions were summarised in the analysis. C3 was situated further away from Saab AB compared to the other points and was supposed to picture the cycling frequency in general in Linköping at each measuring occasion. The other counting points were supposed to picture the cycle flows to Saab AB from different housing areas. The purpose was to compare the cycle flows from Ekholmen with direction towards Saab AB with that from other parts of the city, in order to see whether the improved service level in the test area generated a higher cycling frequency from Ekholmen. Naturally, the starting point and the destination of each counted cyclist could not be established.

RESULTS

The results achieved in the pilot study were limited and uncertain, since the test was performed during a time-period of only a little more than one month. Still, the pilot study fulfilled its main purpose of acquiring experience using unconventional maintenance methods. It was concluded, that the method of using a power broom for snow clearance and brine for de-icing produced a higher level of service compared to the traditional method and was therefore considered of sufficient interest for further research in a large-scale study. The method using graded gravel did not notably improve the service level, and although graded gravel might reduce cyclists’ problems with punctured tyres, compared to abrasives, it may also increase the problem with poor friction on bare surfaces. Consequently, it was decided not to continue using that method in the large-scale study.

In the pilot study and during the first winter (1999/2000) of the large-scale study, the weather conditions were not ideal for the purpose of testing new winter maintenance methods, since it was fairly mild with high average temperatures and less snow than normal. During the second winter (2000/2001) of the large-scale study, there were periods of high snow intensity, but, overall, one could say that this winter was also milder than normal. This means that the results from the studies cannot apply to the typical winter conditions in this region, but perhaps for a region with milder climate and, of course, during winters milder than normal.

Operating experiences

To get sufficiently good results when clearing snow with the power broom, the operator had to maintain a slower speed than during traditional ploughing. Also, in a few stretches of the test area, the pavement was in such bad condition, that it was difficult to get good snow-clearing results, although the power broom was likely more effective on such stretches than traditional ploughing. A great wearing of the broom indicated, that there is a potential in improving the plastic material of the broom. Some other materials were, indeed, tested by the contractors, but without the success of finding a material better suited than the plastic.

During the pilot study, and the first winter (1999/2000) of the large-scale study on occasions with a snow depth over 2–3 cm of loose snow and if the snow was very wet, the power broom showed problems clearing the snow. The effect of the power broom was improved by adding an extra hydraulic engine to the maintenance vehicle before the second winter (2000/2001) of the large-scale study. This improved the snow clearing results considerably and, at almost any snow depth, the snow could swiftly be swept away. Still, the operator had to maintain a slower speed than during traditional ploughing. At too high a speed, snow was thrown backwards at the windshield of the maintenance vehicle reducing the visibility of the operator.

One of the main cycle routes from Ekholmen to Saab AB comprised a link where cyclists had to use the roadway. This section was more difficult to clear from snow and ice compared to other sections comprising separated cycleways. Snow and slush remainders were thrown to the side by cars on the roadway and accumulated by the curbs in the area allocated for cyclists. The cars also packed the snow faster than on separated cycleways and generated a more slippery surface.

At some occasions, there were problems regarding regelating de-iced cycleways. One reason for this might have been an uneven spreading by the spinner used during the large-scale study. In the pilot study, a spraying boom was used instead with nozzles evenly spraying the brine over the surface.

Observations of road surface condition

During each winter of the large-scale study about 20 road condition observations were performed on each selected cycleway section. In Figure 1, the road conditions observed on cycleway sections within the test area (T1 to T6) are compared to those observed on the control sections (C1 and C2). Not all sections were observed at every occasion, which explains the differing height of the bars. In addition to the controls just outside the test area, C1 and C2, two controls further away from the test area, C4 and C5, were also observed. However, observations were not performed at the same occasions of these control sections and are, therefore, not comparable with the ones performed in the test area. Thus, these observations are not included in Figure 1.

During both winters, the road condition observations showed, that the maintenance service level was almost consistently higher in the test area compared to the controls outside the test area. During the first winter, 1999/2000, bare surface was found at 52 to 76% of the observations performed on cycleway sections in the test area compared to 12 to 15% at the control sections. The corresponding amount of bare surface during the second winter (2000/2001) was 52 to 70% and 13 to 17%, respectively. However, due to the hygroscopic qualities of salt, the bare surfaces in the test area were often wet. It should be mentioned that the road condition observations were conducted after, or during, almost each occurrence of snowfall or hoarfrost and, thus, the results in Figure 1 do not represent the conditions prevailing over the winters. Road conditions representative for the winters of the study would have shown a higher share of bare surfaces, both in the test area and at the control sections.

Section T3 comprised the section where cyclists had to use the roadway. As already mentioned, this section was more difficult to clear from snow and ice compared to separated cycleways. The observations performed during the first winter of the large-scale study also showed, that this section more often showed snowy and icy road conditions compared to the other sections of the test area (Figure 1).

Measurements of friction

The friction measurements, performed both in the pilot and large-scale study, showed, that the friction level on the cycleways maintained with the “brine method” was considerably higher than on cycleways maintained traditionally. At the time of the measurements, the surface on the cycleways included in the test was bare and wet and there was snow on the cycleways used as control. It is not surprising that a snowy surface is more slippery than a bare surface. Nevertheless, this showed that the test method using a power broom for snow clearance and brine for de-icing resulted in a surface less slippery than would be the case with the maintenance methods normally used.

Questionnaire survey

Of the questionnaires distributed among the employees living in Ekholmen, as well as in the chosen control areas, 570 answers were received, representing a total response rate of about 70%. Men were in majority representing 78% of the respondents, which was not surprising considering the type of workplace chosen for the study. Although the survey was supposed to include only respondents living within 5 km from Saab AB, almost one fifth of the respondents stated that they lived further than 5 km away from work. Four persons even had more than 10 km to work. The majority (65%) lived at a distance of between 3.1 and 5 km from Saab AB and about 16% had 3 km or less to travel to work.

According to their mode choice for journeys to work in summer and winter, the respondents were divided into different categories of “cyclist”: “winter cyclist”, “summer-only cyclist”, “infrequent cyclist” and “never cyclist”. A *winter cyclist* is defined as a person, who uses a bicycle for travelling to work at least two cases out of five during the period from November to March. A *summer-only cyclist* is defined as a person, who uses a bicycle for travelling to work at least two cases out of five during the period 1 April to 31 October, but less during the period from 1 November to 31 March. An *infrequent cyclist* is a person, who cycles only occasionally, that is fewer than two cases out of five when travelling to work, no matter the season; and a *never cyclist* is a person never uses a bicycle for a journey to work. In the survey, 51% were winter cyclists, 24% summer-only cyclists, 9% infrequent cyclists and 16% never cyclists. It should be noted, that the large number of winter cyclists in this survey is probably higher than for an average Swedish workplace.

When asking how well winter maintenance of cycleways, in relation to certain road condition factors, had been performed during the winter of 1999/2000, winter cyclists from the test area of Ekholmen were found to be more satisfied, compared to winter cyclists in the control areas (Table 2). In this case, the amount “satisfied” is the amount of respondents answering “very good” or “rather good”. Table 2 also shows the number of winter cyclists, received answers, and distributed questionnaires in each housing area.

A majority of winter cyclists in the test area thought, that the maintenance service level during the large-scale study in 1999/2000 was higher compared to earlier winters (Figure 2). Also in the control areas, many winter cyclists thought that the service level of cycleways had improved during the test winter of 1999/2000. However, the number was not as striking as for the test area of Ekholmen. It should be mentioned, that winter cyclists in the control group of Hjulsbro (the first control group in Figure 2) were to some extent affected by the test, since the last part of their cycle route to Saab AB was located within the test area. Of winter cyclists in Hjulsbro, 63% stated that a major part of their trip to work was undertaken on the cycleway network included in the large-scale study and maintained with the “brine method”. For Ekholmen, the corresponding amount was 85% and for Hackefors and Vasastan, it was 17% and 11% respectively.

Even though most of the winter cyclists living in the test area were satisfied with the maintenance of cycleways provided during the winter of 1999/2000 and thought, that it had been better compared to earlier winters, 44% were against the use of salt on cycleways. However, the attitude towards the use of salt on cycleways was more positive within the test area compared to the control areas. Of winter cyclists living in the test area of Ekholmen, 43% were positive to the use of salt on cycleways compared to 23% of winter cyclists in the control areas. Including all respondents from Ekholmen (not only winter cyclists), 36% were positive. In total, all respondents included, 26% were positive to the use of salt on cycleways, 53% were against its use and 20% were uncertain. Of all winter cyclists 32% were positive to the use of salt compared to 22% of both summer-only and infrequent cyclists and 16% of never cyclists. In general, the more a respondent had cycled on the cycleways in the test area, and thus had experienced the use of salt on cycleways, the more positive he/she was to the use of salt on cycleways. The environmental concern was the main reason given by the majority of those being against the use of salt. Another commonly stated reason was material damages such as cars or bicycles rusting.

In the survey, 43% of the respondents stated that they would cycle more (13% a lot more and 30% some more) during the winter, if the maintenance service level of cycleways was improved. A total of 62% thought that winter maintenance on cycleways needed to be improved, 12% thought it was satisfactory and 25% were uncertain or without an opinion. Naturally, most of those who were uncertain or without an opinion were those, who did not cycle to work. This also applied to those, who were satisfied with winter maintenance. In the questionnaire, the respondents were given the opportunity to specify how winter maintenance on cycleways should be improved. Most of the comments (162) suggested improved skid control, for example: “gritting should be done more often”, “prevent slush from creating frozen tracks” and “use salt on cycleways”. Better snow clearance, such as “clear the cycleways more often” and “clear the cycleways earlier in the morning” was suggested in 141 of the comments. In addition, some brought up the importance of continuous clearing of cycle routes, not leaving some parts uncleared.

Bicycle counts

In Figure 3, the bicycle counts performed within the large-scale study are presented. When the direction is not given, the bars for T1 and T3 represent all cyclists passing the counting point. Because counts were not conducted exactly the same time at every point at all occasions (Table 1), the cycle flow during one hour only is presented. For January 24, 2001, the number of cyclists counted between 7 and 8 a.m. are presented, and for all the other occasions, the number of cyclists between 6.30 and 7.30. The cycling frequency was strongly correlated to the time of the day, and it is, therefore, difficult to compare the measurements conducted in January 24 with the others. Note also, that counts were not performed at every point at all occasions.

The random variation proved to be too great for drawing any far-reaching conclusions of the bicycle measurements. Nevertheless, some indications concerning the importance of the road and weather conditions for the cycle flow can be discerned from Figure 3. For example, the cycling frequency decreased from March 7 to March 9, 2000 in almost all measuring points and directions, except in the direction from Ekholmen to Saab AB in point T1. One conceivable explanation might be the difference in road condition between the cycleways in the test area of Ekholmen (moist bare surface) and other cycleways (snow and ice) on March 9. On March 7, the road conditions were rather good on all cycleways, both in the test area and elsewhere. In February 27, the temperature was –14 °C, which was a lot lower than during the other measuring occasions (Table 1). The low temperature, is probably the primary reason for the lower cycling frequency at this occasion compared to the other occasions when measuring was performed.

Comparisons of costs for winter maintenance measures

Since the large-scale study was just a test performed over a relatively short period of time, it is difficult to do a fair comparison of the costs using the unconventional “brine method” with the costs using a traditional method. Nevertheless, based on several assumptions, cost estimations were made. The calculations were, however, limited to operational costs with no concern to secondary values, such as costs and benefits for the road users.

First, the maintenance costs for the winters of the large-scale study were calculated, on the basis of the number of occasions needed for each type of maintenance measure and their unit prices. The unit prices represented the invoice amount from the contractor, including personnel, chemicals used, etc. The capital cost of the equipment was not included. Secondly, the calculated costs of the large-scale study were adjusted to “normal” winter conditions, based on estimations by the contractor of the average number of measures needed during a winter in Linköping. Both winters in the study were milder than normal and hence the actual costs likely underestimated what would be the “normal” cost.

It was found that, for the winter of 1999/2000, the “brine method” was about 3 times more expensive than the traditional method, and for the winter of 2000/2001 it was about twice as expensive. The higher costs using the “brine method” were mainly related to more occasions of measures needed due to tougher starting criteria. Snow clearance was started at a snow depth of 1 cm instead of 3 cm, and actions were taken at occasions of hoarfrost. The greatest financial earnings from using the “brine method” were the savings related to the suppressed need to remove abrasives and sand from gritting.

DISCUSSION

Road condition observations, measurements of friction and a questionnaire survey presented in this paper, showed, that the method using a power broom for snow clearance and brine, or pre-wetted salt, for de-icing produced a higher maintenance service level than methods traditionally used on cycleways in Linköping. In particular during spring, in combination with the midday thaw, this method proved to be efficient for clearing cycleways. Thus, the “brine method” is probably a good method for regions like Linköping with low snow accumulations but with major ice formation problems. Many other municipalities in southern Sweden have winter conditions of this kind. Also in regions with a colder climate such as in northern Sweden, this method is probably advantageous during spring and fall, when the temperatures are higher and the amount of snow is less. During mid winter, however, other methods are likely to be better suited.

To obtain a higher level of service but also for the equipment to work properly when using the “brine method”, snow clearance must be started earlier than with a traditional method. If the snow has adhered to the road surface or the snow depth gets to high, the power broom might fail to clear all the snow, and the use of brine will not be sufficient to prevent a slippery surface. Therefore, besides the new equipment, tougher starting criteria are needed. In the large-scale study, a starting criteria of 1 cm of loose snow was used compared to 3 cm in the traditional method. This might have been too tough, thereby generating higher costs than necessary. Further studies are needed to find the optimal starting criteria providing the best level of service at the lowest possible cost.

Mostly because the “brine method” requires more occasions of measures since it entails tougher starting criteria, it is more expensive than traditional methods. However, increase of the costs of 2 to 3 times using the “brine method” instead of a traditional method, as calculated from the study, is probably an overestimation of the actual cost. The initial cost with a test like the large-scale study is likely to be higher than the cost with a fully implemented method. Furthermore, it is probably more expensive to use a specific method for a small area only, but still, the “brine method” will be more expensive than a traditional one.

A majority of the winter cyclists living in the test area were satisfied with the maintenance service level achieved with the method using a power broom for snow clearance and brine for de-icing and thought that it was improved compared to earlier winters. Nevertheless, many cyclists were still against the use of salt on cycleways. The fact that the attitude towards the use of salt on cycleways was more positive within the test area compared to that in the control areas indicates that the advantages of using salt become more evident for the road users when experienced directly. However, if the common opinion of the public is that salt should not be used on cycleways, it can be difficult introduce such a method.

As presented in this paper, the service level achieved with the new maintenance method is considerably higher than with the traditional method. This might give rise to social benefits. The improved standard might attract more people to cycle, which could bring both health benefits and environmental benefits. Benefits for cyclists include the absence of abrasives resulting in less punctures and enhanced safety; between 2 and 10% of all one-vehicle accidents among cyclists during winter are caused by skidding due to loose grit on the surface (*l, 5, 6*). A high service level, in general, decreases the accident risk of cyclists, perhaps levelling out the higher number of bicycle accidents that might be related to increased cycling frequency.

Due to high costs and the public opinion concerning the use of salt, it is not recommended to use the “brine method” on the entire cycleway network. However on certain parts, where cycling frequency is high or where several accidents might occur, this method is advisable, since it produces a higher level of service. When striving for good winter maintenance standards, the structural standards of the pavement should not be forgotten. Potholes or other irregularities that create an uneven surface can negatively affect the result of snow clearance.

CONCLUSIONS

Based on the studies described in this paper, the following conclusions were drawn:

- The method using a power broom for snow clearance and brine, or pre-wetted salt, for de-icing provided a higher service level than winter maintenance methods traditionally used on cycleways in Sweden.
- In particular during spring, in combination with the midday thaw, the “brine method” was efficient for clearing the cycleways. The method has greater potential in regions, such as southern Sweden, with low snow accumulations but with major ice formation problems, compared to regions with a colder climate, such as northern Sweden.
- Snow clearance using the power broom demanded a slower maintenance speed compared to during ploughing.
- The “brine method” was more expensive than winter maintenance methods traditionally used on cycleways in Sweden, mostly due to more occasions of measures required.
- Cyclists did notice the improved maintenance service level provided with the “brine method”.
- It could not be concluded, that a higher maintenance service level generated a higher winter cycling frequency, although cyclists stated, that the road condition was important in their decision to cycle or not.
- Winter cyclists were more positive to the use of salt on cycleways than others, who usually did not cycle to work during winter.
- Those, who had experienced the use of salt on cycleways, were more positive to salting than those who had not.

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LIST OF TABLES AND FIGURES

TABLE 1 Bicycle Counts Conducted within the Large-scale Study

Counting Occasion	Weather Conditions	Road Conditions on Cycleways	Counting Time			
			T1	T3	C1	C3
March 7 2000	Snowfall the morning before, about +4 °C, strong winds.	Dry bare surfaces in the test area, bare or mixed conditions elsewhere.	6.15–8.45	6.30–8.30	6.30–8.30	6.30–8.30
March 9 2000	Occasional snowfall the last two days, about +1 ˚C, no wind.	Wet bare surfaces, or thin layers of snow in the test area, snow and ice elsewhere.	6.00–8.30	6.15–7.30	6.00–8.30	6.15–8.30
January 24 2001	Occasional snowfall the last two days, +1 ˚C, no wind.	Wet bare surfaces in the test area, 2 cm loose snow elsewhere.	6.00–9.00	7.00–9.00		
February 7 2001	Heavy snowfall the day before, rain during the night, +5 °C, no wind.	Wet or moist bare surfaces in test area, melting packed snow or thick ice elsewhere.	6.00–9.00	6.15–9.00	6.00–9.00	6.15–8.30
February 27 2001	Heavy snowfall two days ago, –14 °C, no wind.	Dry bare surfaces in test area, packed snow or thick ice elsewhere.	6.00–9.00	6.00–9.00		6.00–9.00

TABLE 2 Winter Cyclists, from the Test Area and the Control Areas, Satisfied with Winter Maintenance of Cycleways, in Relation to Certain Road Condition Factors

Road Condition	Amount of Satisfied Winter Cyclists				
	Test Area	Control Areas			Total
	Ekholmen	Hjulsbro	Hackefors	Vasastan	
Slush	49 %	48 %	17 %	18 %	28 %
Loose Snow	62 %	54 %	38 %	39 %	44 %
Black Ice	50 %	39 %	28 %	11 %	25 %
Packed Snow/ Thick Ice	50 %	37 %	23 %	13 %	24 %
Total Average:	53 %	44 %	27 %	20 %	30 %
No. of Winter Cyclists	128	54	47	62	291
No. of Answers	214	140	82	128	564
No. of Distributed Questionnaires	303	202	104	220	829

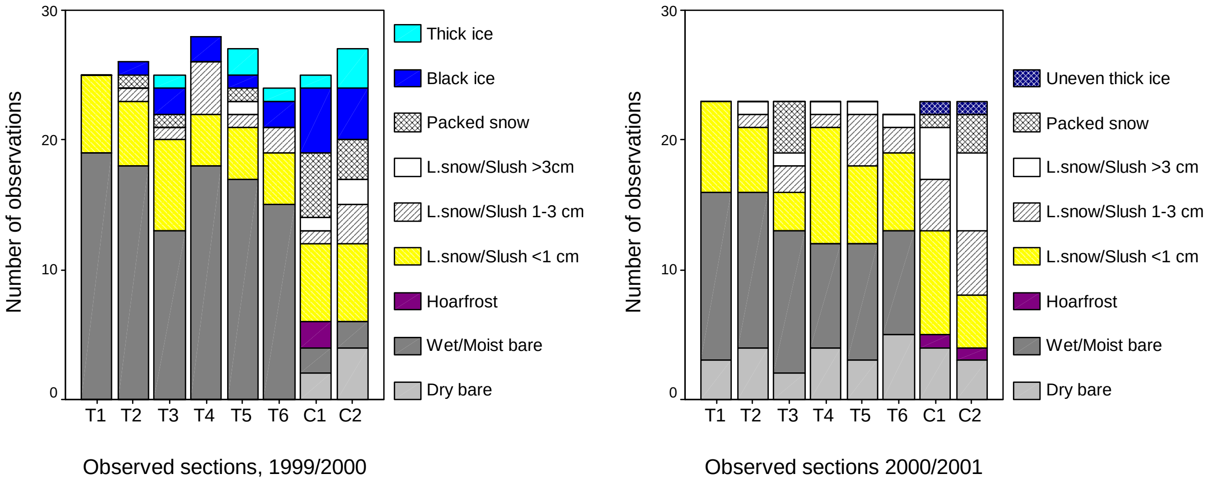

FIGURE 1 Road condition observations performed in the large-scale study at cycleway sections within the test area (T1 to T6) as well as at control sections (C1 and C2)

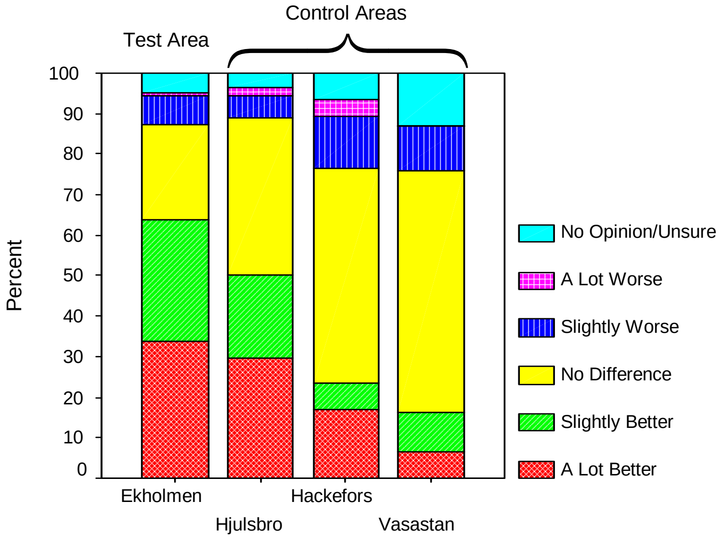

FIGURE 2 The respondents' evaluation of the maintenance service level of cycleways during the test winter of 1999/2000 compared to earlier winters

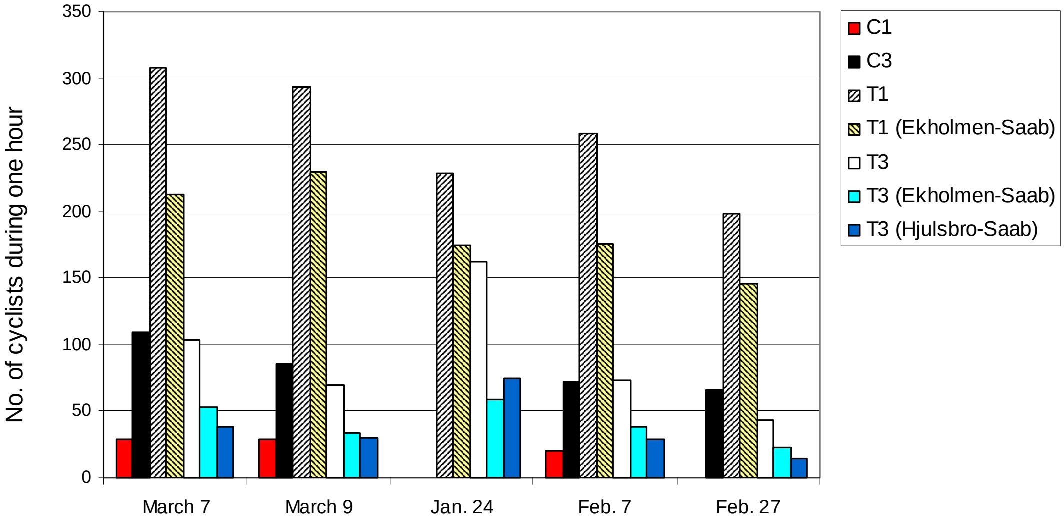

FIGURE 3 Manual bicycle counts performed during the large-scale study - C1 and C3 represent counting points outside the test area while T1 and T3 are located within the test area